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Thermal Infrared (FLIR) Mosaics Of The Lower Little Colorado River and FLIR Instrumentation

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Bureau of Reclamation

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MEMORANDUM

To: Dave Wegner, Acting, Group Manager, Glen Canyon Environmental
            Studies

From: Edmond W. Holroyd III
            Research Physical Scientist

Subject: Thermal infrared (FLIR) mosaics of the lower Little Colorado River
and FLIR instrumentation

The first part of this memorandum is a companion to the one dated 19 September
1994, "Subject: LCR video mosaic", which presented video mosaics taken, on
the morning (07:37-07:52 MST) of 28 May 1994, of the Little Colorado River
(LCR) from the confluence (river mile 0) to about river mile 13. The flight
altitude was at 5000 feet above sea level and a varying altitude (2300 to 1800
feet) above the river. The entire data set was an initial investigation of
the FLIR system for providing calibrated thermal images of the Colorado River
(CR) and LCR for the purposes of detailing fish habitat in the rivers and
adjacent terrestrial habitats. In this report the FLIR data are presented in
similar format and are extended to temperature calculations.

The second part of this memorandum discusses the FLIR instrument itself, ways
to improve its data, comparison with a scanner instrument, and operational
recommendations.

Processing Style

All registration of individual FLIR frames was based on the registration of
the video frames taken at the same time. That, in turn, was based on the
Sites 5 and 15 orthophotoquads. The individual mosaic portions are segmented
by minute of flight time. All are in the Arizona State Plane Central
coordinate system, measured in meters at 0.8 m resolution. The enclosed
prints are at 1:8000 scale so that they fit the page. The original computer
files have more detail.

The prints are not labeled with traditional figure numbers. Flight time and
river mile notations are on each and are summarized in Table 1. Direct FLIR
images are in B&W, with white=warm and black=cool. Temperature
interpretations of FLIR data are in color according to the scale on the image.

Table 1. Inventory of illustration identifications. CR=Colorado River,
LCR=Little Colorado River. The B&W versions are raw FLIR with white=warm.
Color versions are Celsius temperature.

Starting minute MST:	07:37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
River Mile in view: CR	63	62														
LCR		0	0,1	2	3	4	5	6	7	8	9	10	11	12	12.5	13

As before, registration accuracy is least in the black shadows of the
orthophotoquads. It should be best along the river itself. Positions on the
cliffs away from the river must be assumed to have severe perspective
distortions, but this should be irrelevant to the river analyses we are doing.
Warping distortions exist for those frames which depart from rectangular
proportions to parallelograms without right angles. See especially near mile
13.5 (last frames of this series) for an example of severe warping distortions
caused by having no orthophotoquad image for a reference at that location.

All FLIR data were captured at 4 second (3 second on the Colorado River

Contrast=190, Hue and Saturation=200. In spite of this uniformity, a few frames during LCR mile 0 to 1, 07:39-07:40, which were captured at intermediate times, appeared with cooler results. They were put in the background during the mosaic process so as to affect only minor gaps in the regular thermal image data. Though most of the thermal gradient problem (from frame top to bottom) was removed, there remain some minor discrepancies between adjacent frames in some locations.

All FLIR frames were smoothed with a low pass filter of 4 lines by 3 columns to get rid of the line pairing problem. This degrades the resolution of the images but improves the image quality significantly.

The SML (Spatial Manipulation Language) routine written for MIPS processing of the FLIR images into temperatures is below. Its output (T) is integers whose value is ten times the Celsius temperature for each pixel, but at a resolution of 0.2 C. Thus a pixel value of 156 indicates a temperature of 15.6 C. There will be no odd valued pixels. The equation for T removes most of the thermal gradient in the image. Different equations are needed for other portions of the Colorado River because different gain and offset settings were used there.

```
GetInputRaster(A)
GetOutputRaster(T,NumLins(A),NumCols(A),RastType(A))
SetScale(T,LinScale(A),ColScale(A))
CopySubobjects(T,A,1)
for lin=1 to NumLins(A) begin
   line=lin+(342-NumLins(A)) # adjustment for variable line totals in raster
   for col=1 to NumCols(A) begin
     T[lin,col]=2*round((161.6*A[lin,col]+10.01*line+34830.)/(0.2*line+628.2))
   end # of column scan
   if((lin%10)==0) then print "line",lin," of ",NumLins(A),"; T2"
end # of line scan
```

As before, each mosaic segment was initialized by starting with a 100x100 meter chip from the orthophoto map, oriented to north at the top and resampled to an 0.8 m pixel size. The original FLIR frames have resolutions of about 0.38 horizontal to 0.45 vertical m/pixel.

A few frames were warped with the slower but more accurate plane projective transformation when the affine warping produced a computer crash during the mosaic process. This apparently creates data consistency variations of up to a few meters near the river. It substitutes more accurate warping and positions for the inferior affine warping of most of the data set.

The computer version gives the annotation a numerical value of 0 (black) or 255 (white). An ERDAS version is being generated for Patrick Wright for reference.

Discussion

Several springs with temperatures warmer than the LCR were found in this sequence. A separate memorandum will address them later. The river temperature varied between about 19 and 22 C, depending on proximity to warm springs. Moist shores were usually cooled by overnight evaporation to as low as 16 C. This enables a mapping of areas with a close water table. Dry shores and elevated cliffs and rocks had temperatures related to heat retention or radiational cooling.

Early morning vegetation temperatures were variable. The video quality was inadequate for identifying plant types, such as separating grass and shrubs. Many plants were warmer than the soil but others were indistinguishable. Future flights may still provide thermal differences between plant types. Soil moisture may be responsible as well as the diurnal variation of plant metabolism. Sunshine generally raised soil and rock temperatures to instrument saturation values and dried out (warmed) moist soil surfaces.

Analysis Recommendations

The enclosed FLIR data set is the best portion of the two flights of 28 May 1994. Most of the rest had inferior gain and offset settings. LCR images from mile 13 to 18 were analyzed for a subsequent report even though no aerial photos are available to help in georeferencing. Morning tape 3 of the Colorado River below the LCR confluence has a salvageable portion for potentially showing temperature gradients in backwaters. The waterfall at Vasey's Paradise is worthy of thermal study though the results will be crude. The rest of the data set should be ignored unless the backwater thermal gradients are small. Hopefully future flights with better calibrations will yield the quality desired for proper assessment of the thermal patterns in the Grand Canyon.

The description of backwater temperature patterns, the main objective of the flight, is not provided here. There are only a few backwaters on the CR portion of this study. The LCR is so shallow, narrow, and irregular in lateral extent that it is difficult to define LCR backwaters. Backwater temperature gradients are being left to a subsequent memorandum which will include much more data (tape 3) below the CR/LCR confluence.

Discussion and Recommendations from Portland trip to FLIR offices

You and I had a good meeting in Portland with FLIR representatives. Our concerns were properly addressed. My perception of the answers is as follows.

(1) The sync and line pairing problems can be fixed by a proper tuning of the instrument before a flight. The thermal gradient problem results from a thermal gradient across the reference area that the instrument uses for internal calibration. That gradient is caused by the proximity of various heat sources and sinks within the instrument. The problem will not go away and needs to be removed by equation, like I did in this study. The basic calibration of gain and offset controls can be done in a laboratory setting. My desire is to label the gain knob with the temperature span achieved after video capture. The offset knob should be labeled with the minimum temperature indicated in the captured data.

(2) The video camera within the FLIR instrument had its blue channel saturated during the mission of 28 May 1994. It appears that such an error can be detected and fixed on future missions by laboratory checking and calibration procedures.

The necessity of the normal color video camera in the FLIR instrument is somewhat unresolved. A quality color video is definitely necessary for proper registration of the thermal images. It is best to have the video and FLIR optics as close together as possible to avoid perspective problems during registration. It may be entirely adequate to use the Tyler-mounted quality video camera normally flown by Reclamation for its video mapping. But there would always be questions about whether the separate cameras were indeed looking at the same view. The independent aiming controls and the different optical field of view angle (zoom factor or effective focal length) suggests that the views will be somewhat different. It may be more convenient, therefore, to use a video camera within the FLIR instrument. I would recommend acquiring a FLIR with an enclosed video camera if the additional cost is not excessive.

(3) An electronic level would be helpful if added to the FLIR instrument. It can be connected to simple indicator lights to show if the view is forward, at, or rearward of nadir. The operator should try to achieve nadir viewing for the particular angle of attack of the helicopter during normal flight conditions for gathering data. Turns and accelerations will be expected departures from nadir. Nadir viewing is best for accurate mapping. Off-nadir viewing requires additional processing and registration and is time consuming to analyze. The problems with off-nadir viewing will be illustrated in a

subsequent memo on LCR data from miles 13 to 18, where there is a lack of georeferencing images.

(4) The FLIR instrument drifts during operation. Most drift occurs during a half hour warmup. Drift problems can be minimized by operational procedures and calibration recordings.

(5) The image bleeding noticed on the afternoon flight degrades sharp transitions between hot and cold portions of an image. This is normal for any sensor system and reflects response time characteristics of many parts of the data system. The effect may come from the thermal sensors, the electronics that read the sensor voltages, the writing or reading processes on the tape recorder, or the video capture board, or a combination of them all. There is essentially nothing that can be done apart from a major (and unlikely) engineering change in the various components.

Operational Recommendations

For Grand Canyon use out of the Flagstaff airport, the instrument should be operated continuously after takeoff. The gain and offset should be adjusted in advance for the expected thermal range to be examined. The flight should hover initially over the confluence of the Colorado River and LCR to confirm the adequacy of the gain and offset settings. A slight drift in position is probably best so that the unaltered warm LCR water is fully visible in some views and the well mixed cold Colorado River water is fully visible in others. The island itself and the mixing water streams are of no use for calibration. That first look should be recorded on tape as a calibration setting. The canyons should then be flown, though the recorder (not the FLIR) can be turned off during the flight portions getting to the starting point and returning from the ending. The flight may pass over the confluence again during normal data recording, giving a second calibration point. At the end of the flight the helicopter should return to the confluence and the recorders should be turned on again for a final calibration. The presumably three or more confluence checks recorded on video tape should allow for a correction of the known thermal drift of the FLIR instrument with time.

Only the water temperatures of the main Colorado River and within the LCR near its mouth need to be monitored by instruments in the rivers. Additional recording sites are probably not necessary. The FLIR sees only the top skin temperature of the water, so thermometers should be near the top or else in mechanically well mixed portions of the rivers.

The pilot should be able to see a monitor of the color video image so that he can keep the river within view. The flight on 28 May was flown at the 5000 foot pressure altitude (about 2100 feet above the river) so that the meandering river would mostly be kept in view. That strategy was successful. Letting the pilot use the monitor would allow flying at a lower altitude for better resolution. However, it would also increase the analysis time by requiring the capture of more frequent frames for full river coverage with no gaps between captured frames. If a high resolution view of a backwater, for example, is needed, perhaps the helicopter can hover over it while the FLIR is temporarily switched to its 4X zoom view. After seeing the soil moisture cooling effects in the present data set, my preference is to stay about 2100 feet above the river and get a wide view including whatever is adjacent to the river. The viewing angle of the FLIR and enclosed video camera is apparently narrower than the view of Reclamation's usual mapping video camera, therefore requiring a higher flight altitude.

Parts of the LCR canyon are too narrow for viewing from the 5000 foot pressure altitude. There are often high rock tables that obscure the meandering river below. The gaps in the rock are less than the river width. A flight strategy for the future might be to fly up the LCR at the normal 5000 foot pressure altitude, getting a uniform record for normal registration. The return to the confluence (for the required calibration drift documentation) could be flown

as close as is safe above the narrow gap in the rocks to get a full view of the river below.

It appears that future flights above the LCR should be as close to dawn as practical to record overnight thermal equilibrium conditions. This produces deep shadows in the video images, but the automatic light level device in the camera adjusts the scene brightness enough to make the landmarks visible.

FLIR/Scanner Comparisons

As flown, the FLIR data after capture gave us pixel sizes ranging about 0.65 to 0.50 m horizontally and 0.50 to 0.35 m vertically, depending on flight elevation above the river. For the flight segment near LCR river mile 15 the scales were about 0.55 m and 0.40 m, respectively, for a height of about 1750 feet above the river. Normalizing that to a standard 1000 m above the river, the pixel sides would be 1.03 and 0.75 m, respectively. The field of view, when captured with a Vision-16 board and the MIPS software, is about 350 lines by 512 columns. The width of view is 528 m at the 1000 m height. Actual analysis resolution is coarser because of the filtering, which may not be required on future missions. The images appear to be compressed at the left and right edges because of the geometry of scanning the scene with a rotating mirror. Temperature resolution has been set in the analysis at 0.2 degrees Celsius, slightly coarser than the 0.16 specified for the FLIR instrument. That is entirely adequate for our river studies.

Dave Eckhardt provided some values for a Daedalus Airborne Multispectral Scanner that was used on the Green River at a later date. Flying at a height of 1000 m above the river, the pixel size would be 2.093 m x 2.093 m at nadir and 3.908 m x 2.860 m at the maximum scanning angle of 43 degrees off nadir. These are about twice as coarse as the unfiltered FLIR pixel sizes. There are 716 pixels per scan line, somewhat more than the FLIR image has. The ground swath width is 1.86 times the height above ground, or 1860 m for the 1000 m standard height. That is much more than is generally needed for river work. The river would only be a small fraction of the recorded data. The scanner is internally calibrated with two selectable reference temperatures, but operator error with the control dials can put either or both controls outside of the data range, as happened on the Green River flight. Its temperature resolution is not listed in the promotional material but is presumably similar.
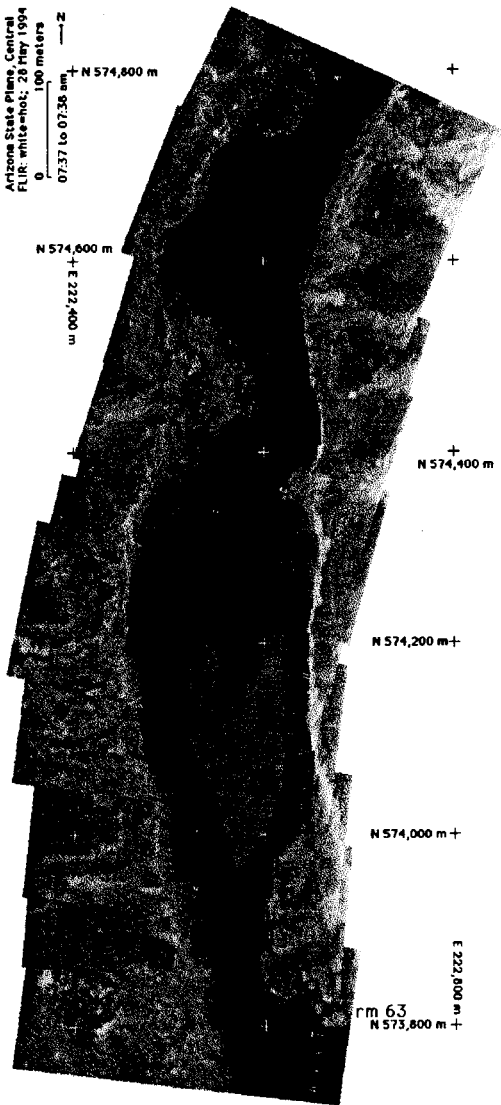
The FLIR and video capture images like a camera in that a full X-Y field of view is seen in a small fraction of a second. A scanner gathers its data line by line perpendicular to the flight direction as the aircraft flies along a straight line. A gyro mount takes out airframe attitude fluctuations up to 15 degrees off nadir. To use the scanner to monitor the Grand Canyon region the aircraft would have to fly high enough, perhaps above the rim, so that the Canyon could be observed from a series of <u>straight</u> flight line segments. It appears that, for proper navigation purposes, the aircraft flying a scanner will need to fly at least as high as the altitude used for the FLIR (like between CR miles 0-25 where the rim is low and near Unkar Rapids where the canyon is wide) and up to twice as high (where the canyons are deep and narrow, like the LCR, or twisting). That means that scanner data will always be twice to four times coarser than FLIR data and will record data greatly in excess of the river width and adjacent bottom land. The FLIR has a 4X zoom for finer detail from the same flight altitude, but the scanner must be flown at a lower altitude to achieve such resolution. The Canyon presents operational difficulties for lower flight altitudes, especially for the straight and level flight required for use of scanner data.

The studies of FLIR data have shown that the instrument is entirely adequate for monitoring the water temperature patterns in the Grand Canyon system. It is less expensive to purchase. Purchase prices for a new FLIR unit are nearly $137K. A Daedalus Airborne Multispectral Scanner costs about $650K. Free data from either unit invalidates cost comparisons. The FLIR has finer horizontal resolution than the scanner by factors of two to 4, with an

additional 4X enlargement possible. Its use does not require straight and level flight, only a preference for nadir viewing for ease of mapping. Its 0.2 degree C temperature sensitivity is entirely adequate for our purposes. Both the scanner and the FLIR must be carefully maintained, calibrated and operated for reliable data. It strongly appears that the FLIR unit is the better alternative if a thermal imaging instrument must be purchased for river monitoring work.
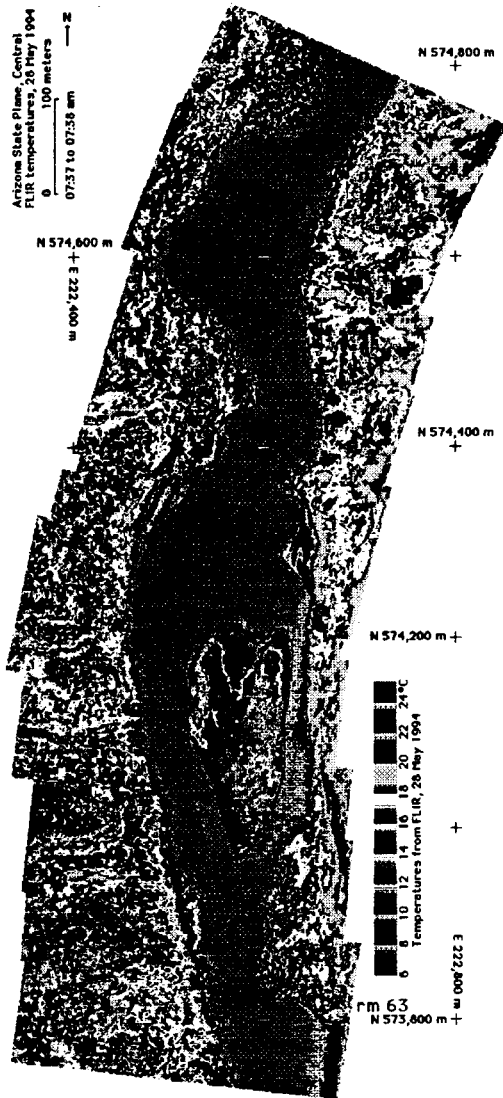
Attachments (FLIR and temperature mosaics)

Arizona State Plane, Central
FLIR: white=hot; 26 May 1994

N ——

0   100 meters
07:37 to 07:38 am

+ N 574,800 m

N 574,600 m
+ E 222,400 m

+ N 574,400 m

N 574,200 m +

N 574,000 m +

E 222,800 m

rm 63
N 573,800 m +

Arizona State Plane, Central
FLIR temperatures, 26 May 1994

N

07:37 to 07:38 am

0   100 meters

N 574,800 m
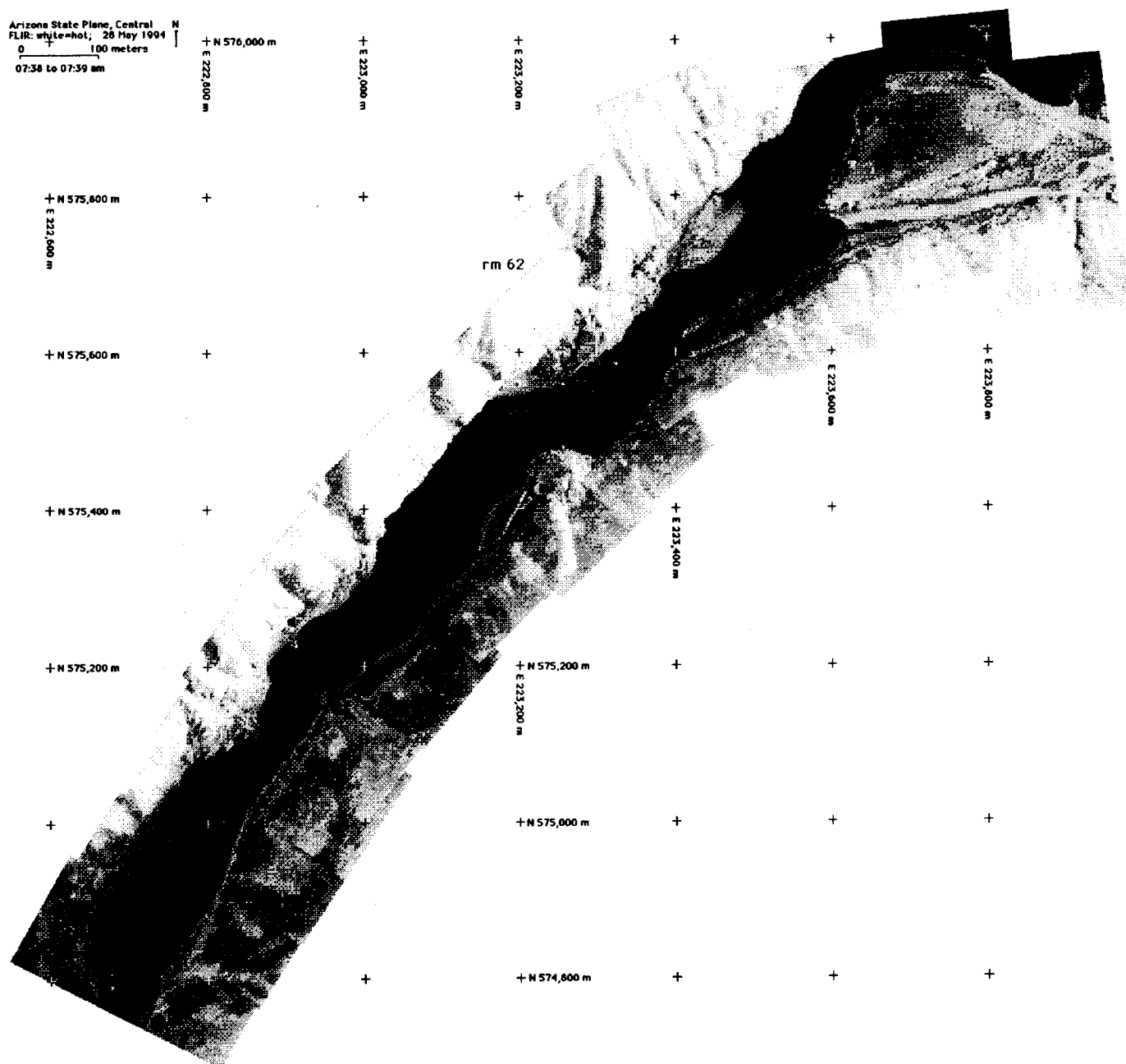+

N 574,600 m
+ E 222,400 m

N 574,400 m
+

N 574,200 m +
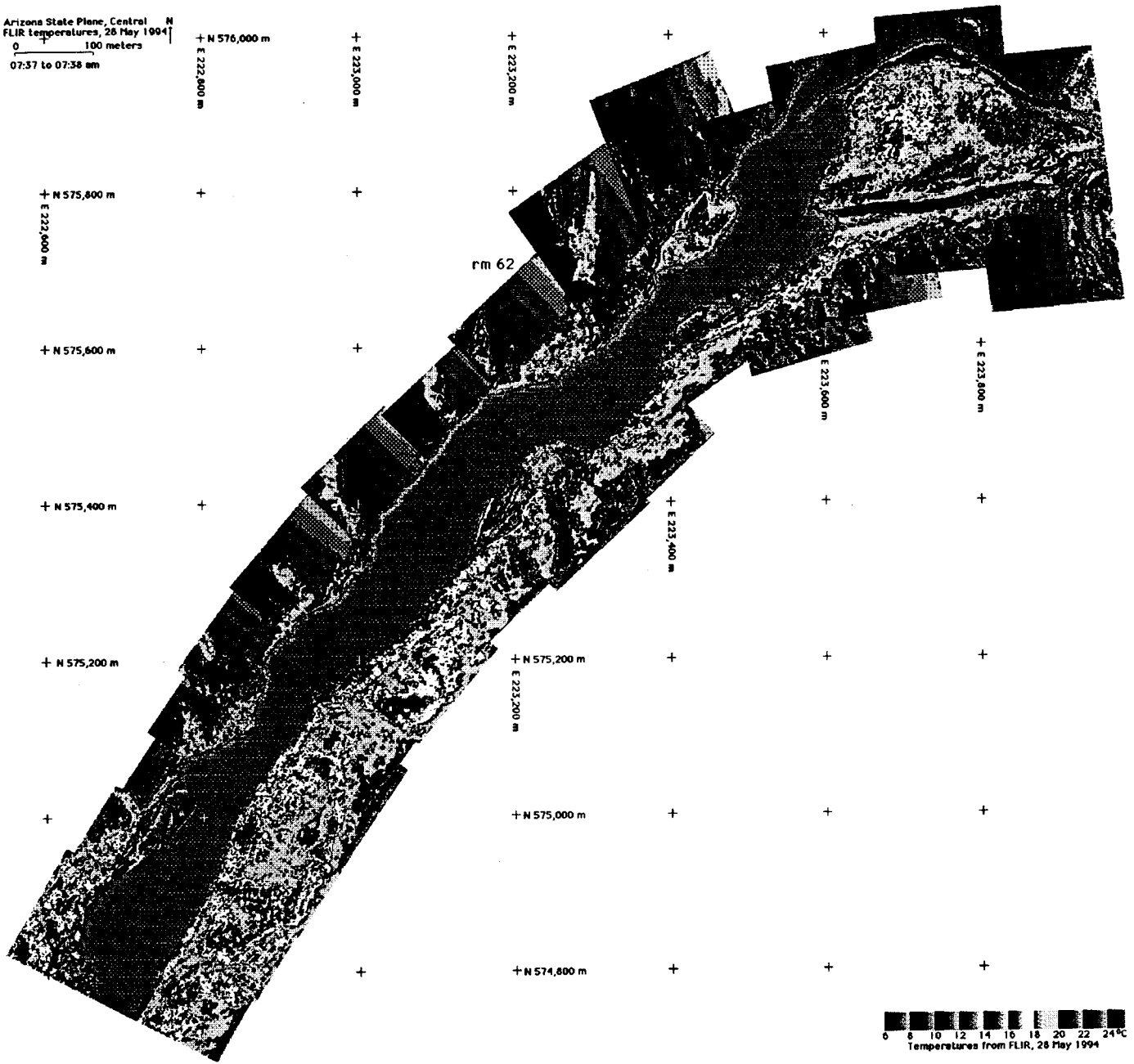
24°C
22
20
18
16
14
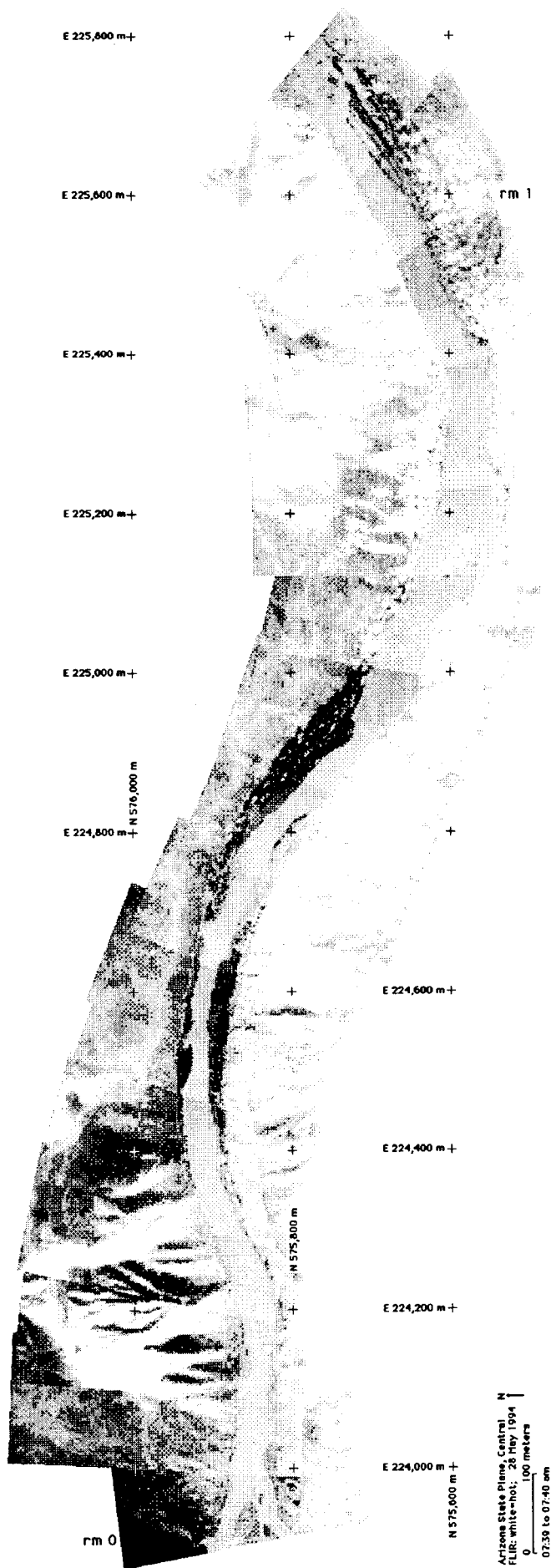12
10
8
0
Temperatures from FLIR, 26 May 1994

E 222,000 m

+

rm 63
N 573,800 m +

E 222,200 m

Arizona State Plane, Central   N
FLIR: white=hot;   28 May 1994
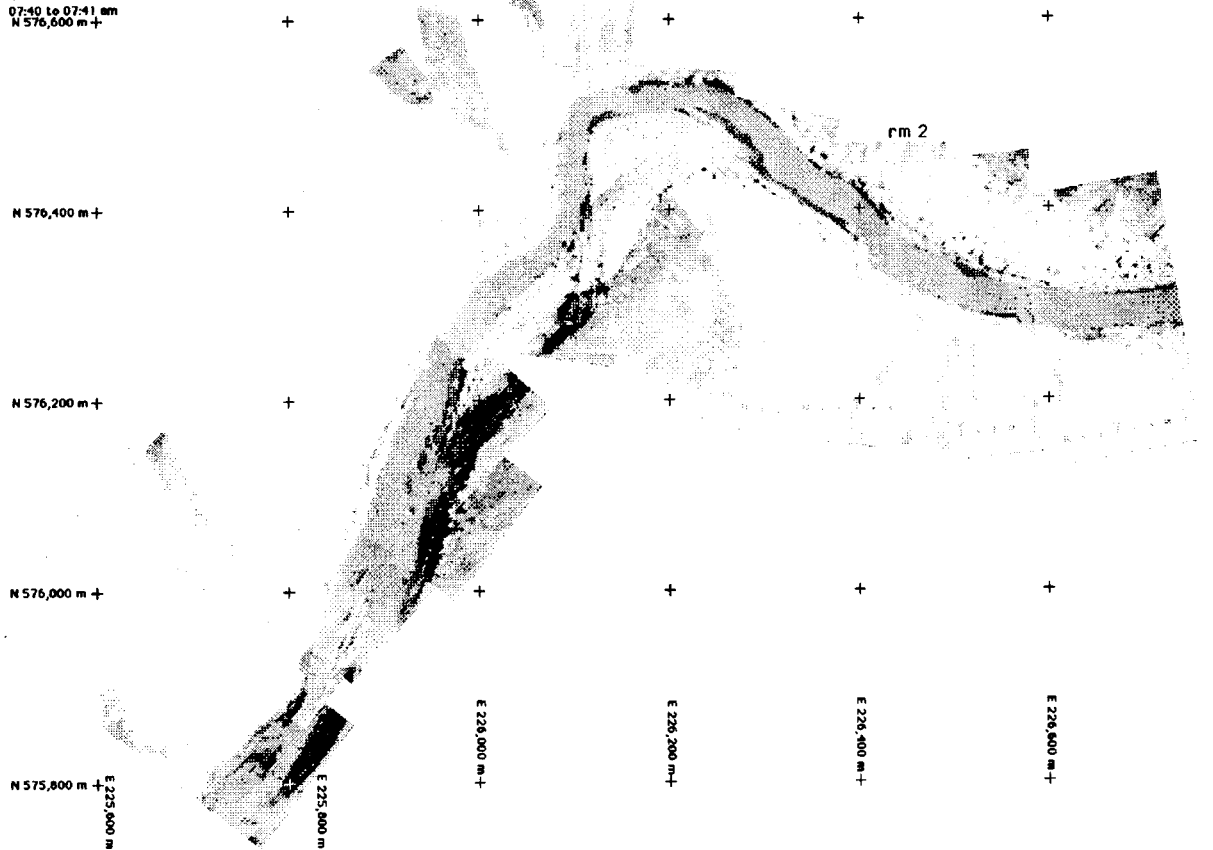0   100 meters
07:38 to 07:39 am

+ N 576,000 m

+ E 222,800 m

+ E 223,000 m

+ E 223,200 m

+ N 575,800 m

+ E 222,600 m

rm 62

+ N 575,600 m

+ E 223,600 m

+ E 223,800 m

+ N 575,400 m

+ E 223,400 m

+ N 575,200 m

+ E 223,200 m

+ N 575,000 m

+ N 574,800 m

Arizona State Plane, Central   N
FLIR temperatures, 28 May 1994
0   100 meters
07:37 to 07:38 am

rm 62

+ N 576,000 m
E 222,800 m
+ E 223,000 m
+ E 223,200 m
+ N 575,800 m
E 222,600 m
+ N 575,600 m
E 223,600 m
+ E 223,800 m
+ N 575,400 m
E 223,400 m
+ N 575,200 m
E 223,200 m
+ N 575,200 m
+ N 575,000 m
+ N 574,800 m

0 8 10 12 14 16 18 20 22 24 °C
Temperatures from FLIR, 28 May 1994

E 225,800 m +

E 225,600 m +   rm 1

E 225,400 m +

E 225,200 m +

E 225,000 m +

N 576,000 m

E 224,800 m +

E 224,600 m +

E 224,400 m +

N 575,800 m

E 224,200 m +

E 224,000 m +

N 575,000 m

rm 0

Arizona State Plane, Central
FLIR: white=hot; 28 May 1994
0   100 meters

07:39 to 07:40 am

E 225,800 m +

E 225,600 m +

rm 1

Arrows mark scenes with
different calibration.

E 225,400 m +

E 225,200 m +

E 225,000 m +

+ N 576,000 m

E 224,800 m +

E 224,600 m +

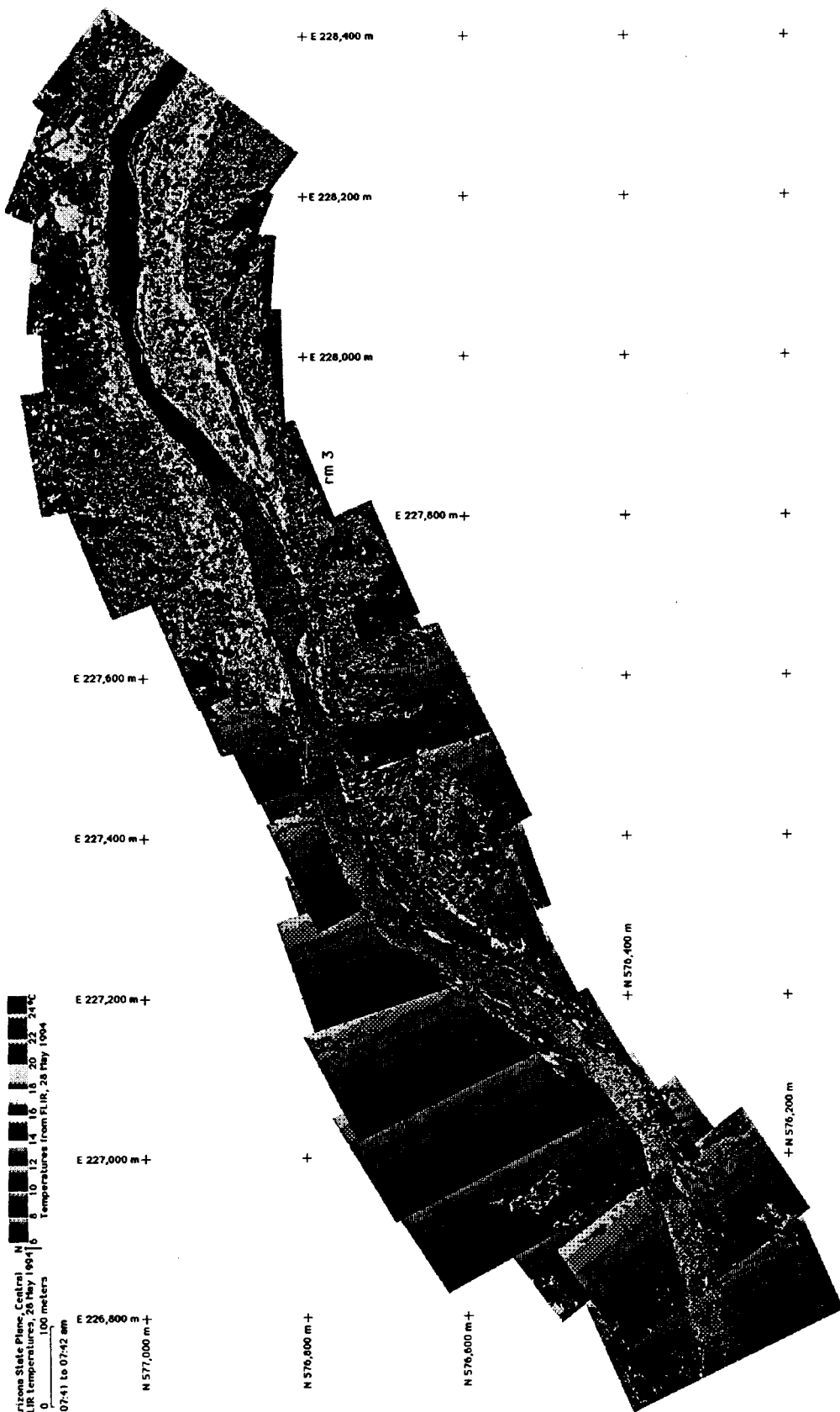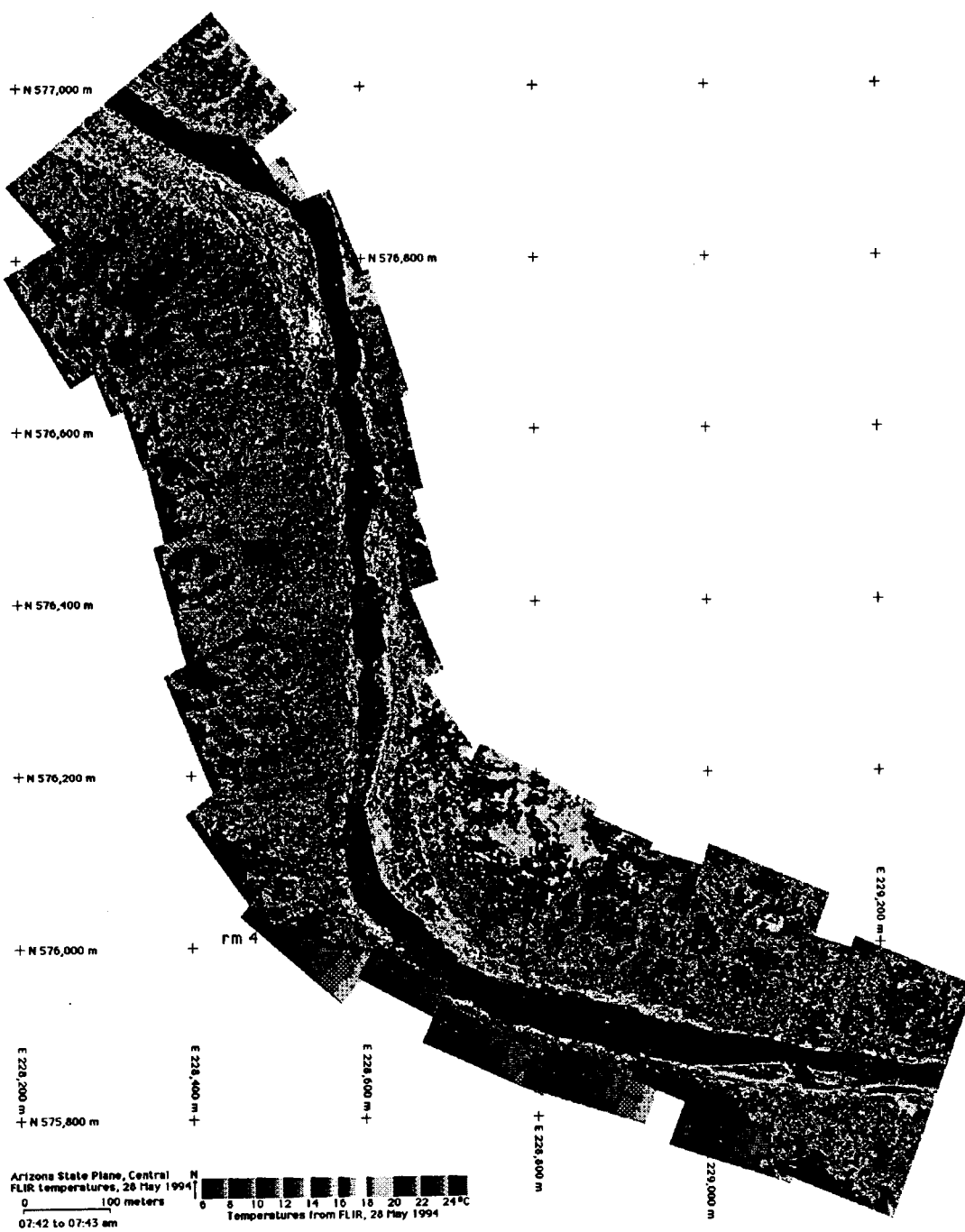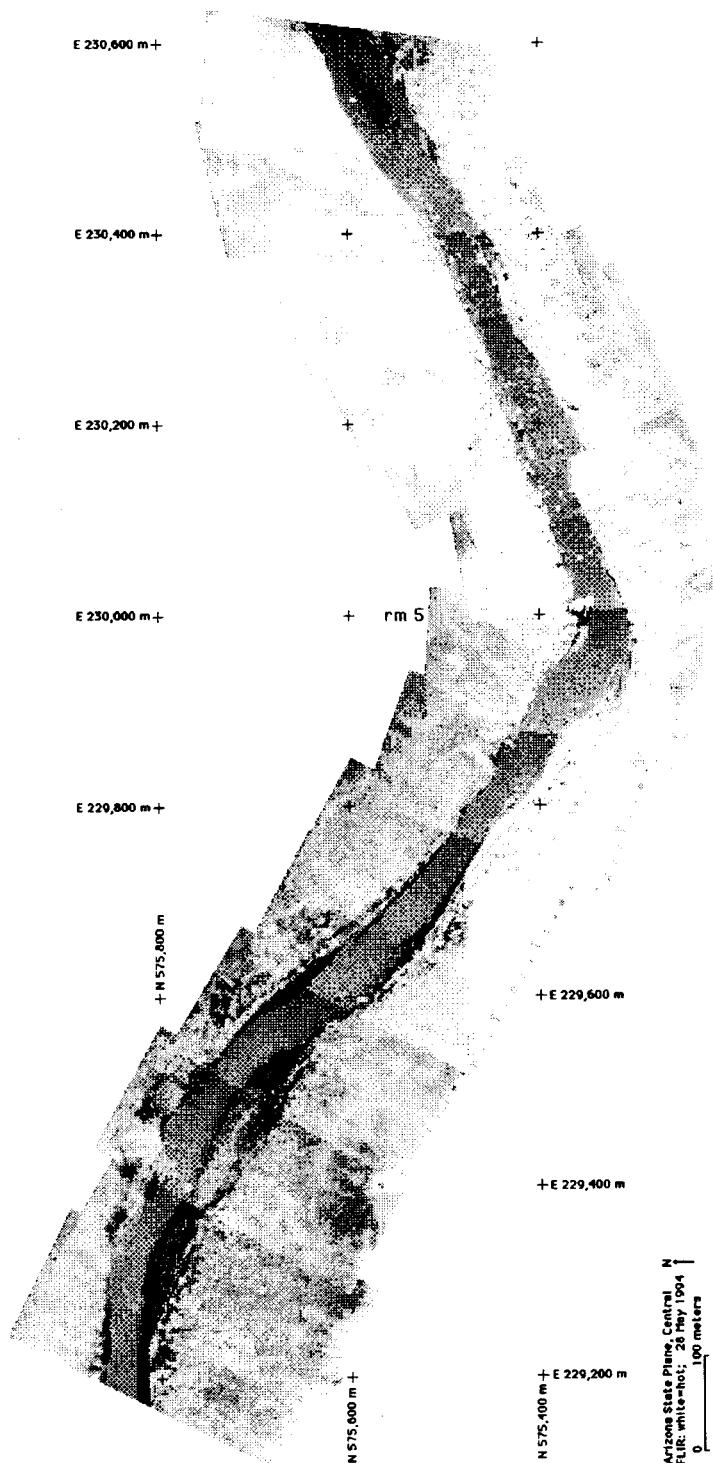E 224,400 m +

+ N 575,800 m

E 224,200 m +

Arizona State Plane, Central
FLIR temperatures, 28 May 1994

N

0   100 meters

07:39 to 07:40 am

Temperatures from FLIR, 28 May 1994

0   8 10 12 14 16 18 20 22 24°C

+ N 575,600 m

E 224,000 m +

rm 0

rm 2

N 576,400 m +

N 576,200 m +

N 576,000 m +

N 575,800 m + E 225,000 m

E 225,000 m

E 226,000 m+

E 226,200 m+

E 226,400 m+

E 226,600 m+

Arizona State Plane, Central   N
FLIR temperatures, 28 May 1994
0   100 meters
07:40 to 07:41 am
N 576,600 m +

N 576,400 m +

N 576,200 m +

N 57

N 575,800 m +

E 225,600 m

E 225,800 m

E 226,000 m

E 226,200 m

E 226,400 m

E 226,600 m

6   8   10 12 14 16 18 20 22 24°C
Temperatures from FLIR, 28 May 1994

E 228,400 m

E 228,200 m

E 228,000 m

rm 3

E 227,800 m

E 227,600 m

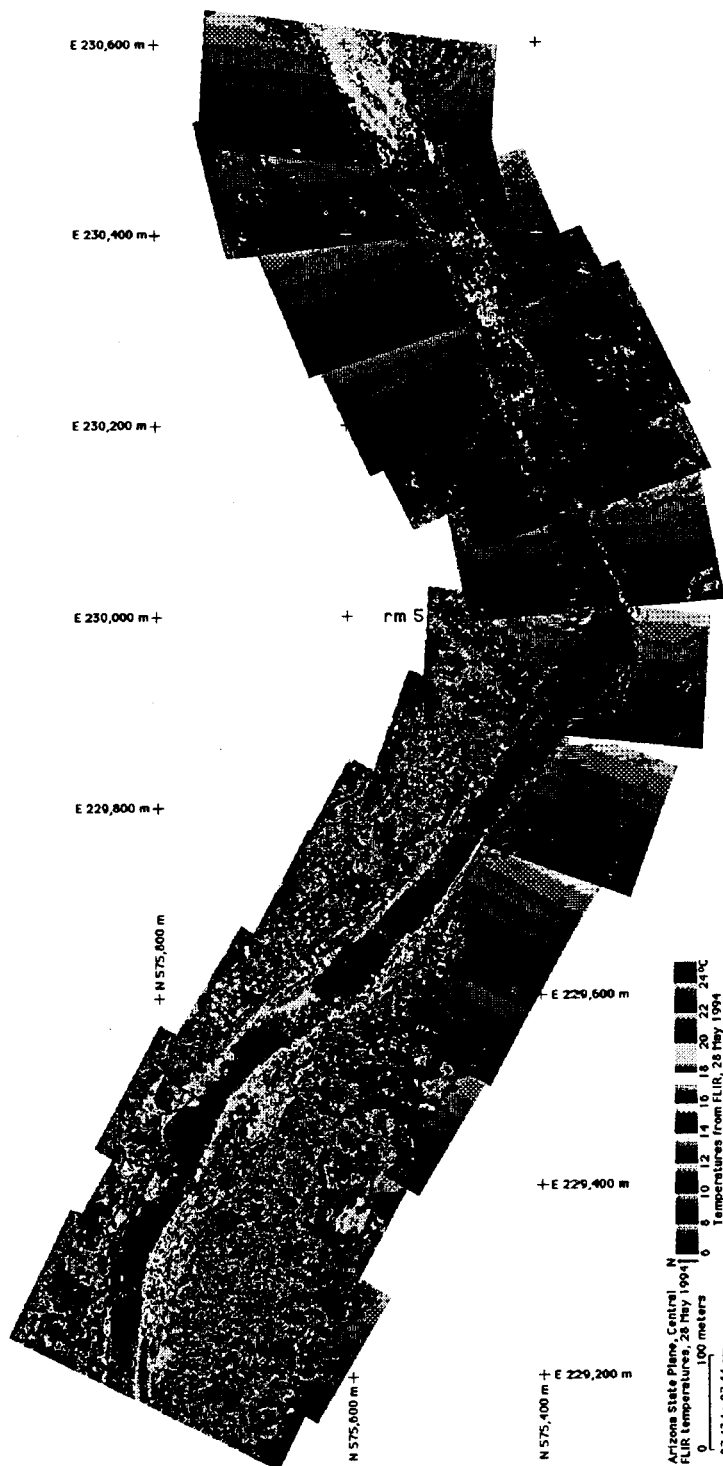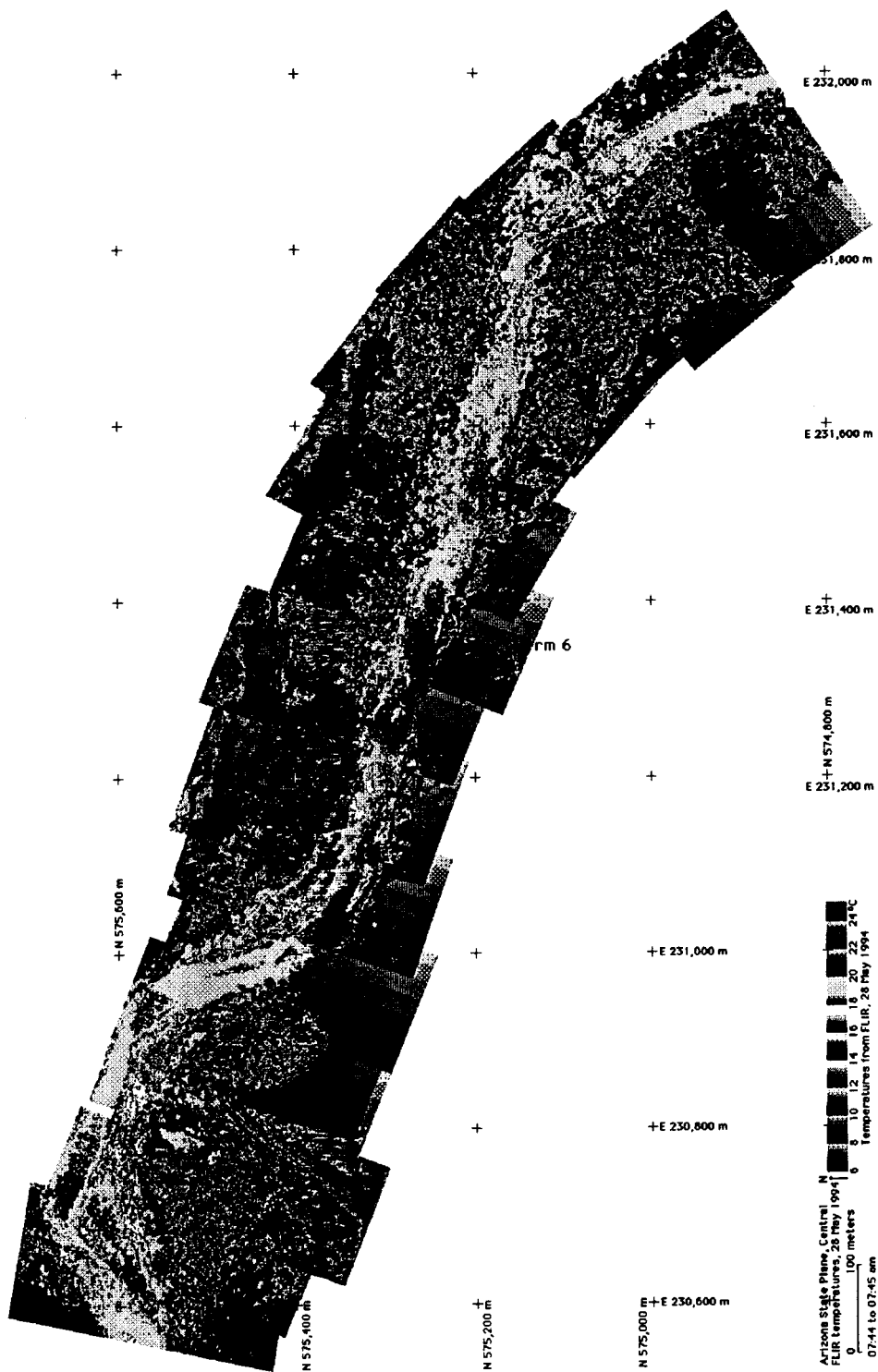E 227,400 m
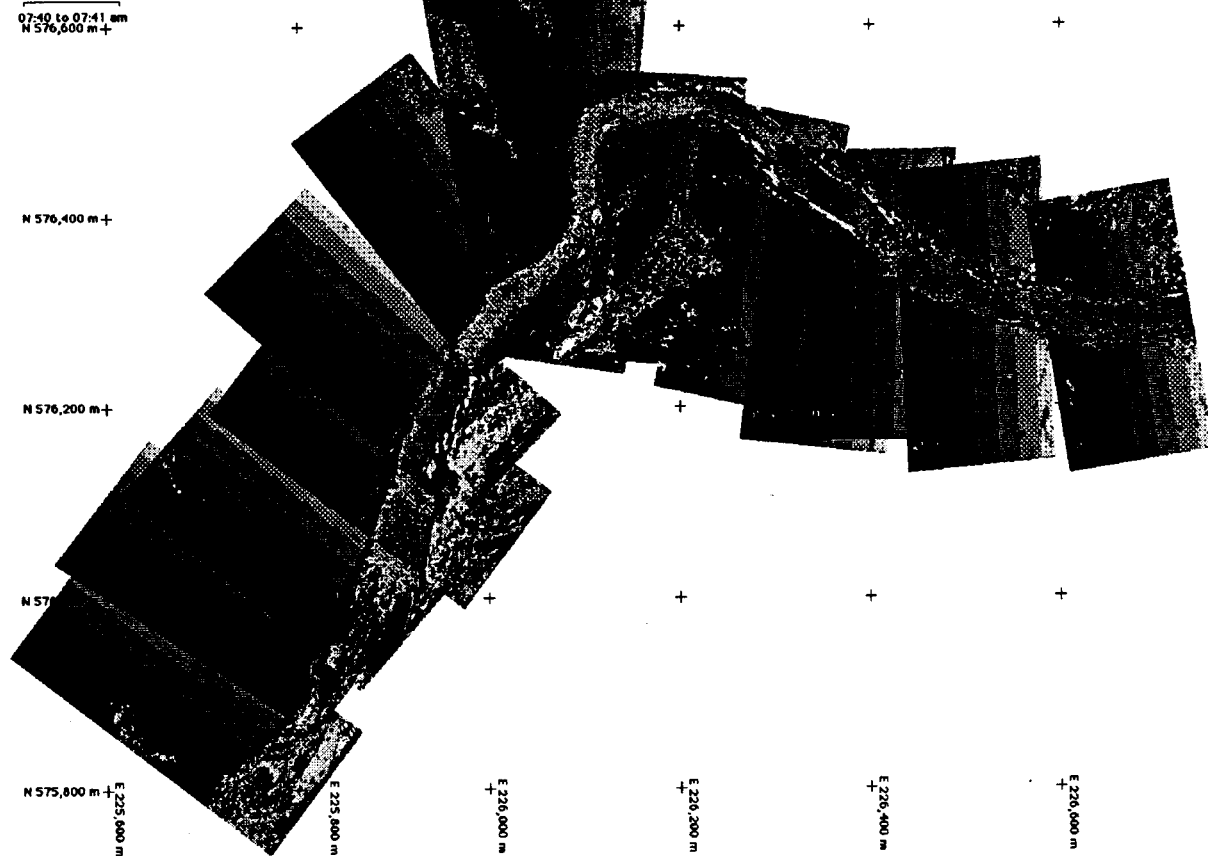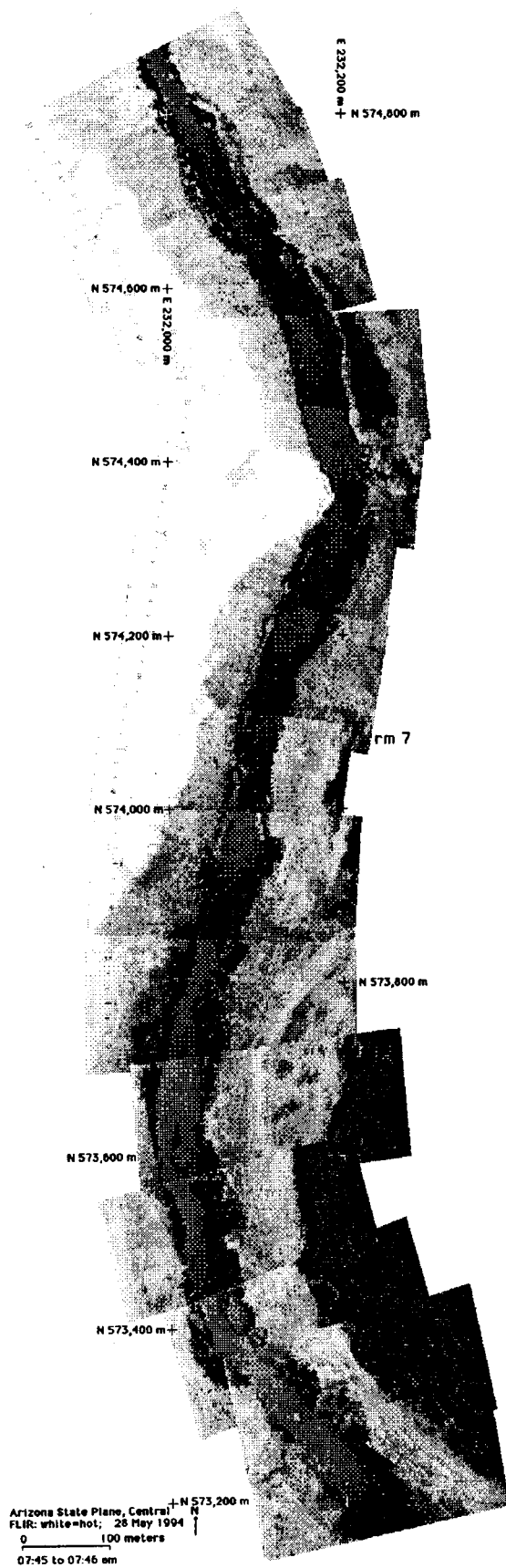
E 227,200 m

E 227,000 m

Arizona State Plane, Central
FLIR: white=hot; 28 May 1994
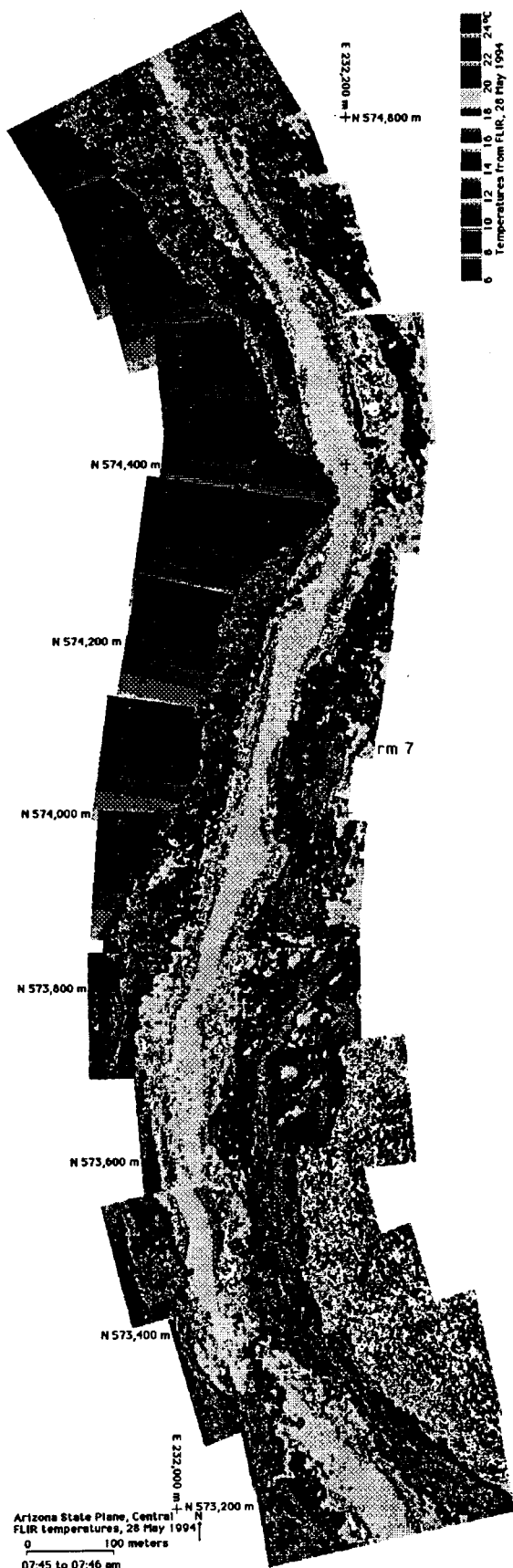N
0   100 meters
07:41 to 07:42 am

E 226,800 m

N 577,000 m

N 576,800 m

N 576,600 m

N 576,400 m

N 576,200 m

Arizona State Plane, Central
FLIR Temperatures, 28 May 1994

07:41 to 07:42 am

0   100 meters

Temperatures from FLIR, 28 May 1994

6   8   10   12   14   16   18   20   22   24°C

rm 3

+ E 228,400 m
+ E 228,200 m
+ E 228,000 m
E 227,800 m +
E 227,600 m +
E 227,400 m +
E 227,200 m +
E 227,000 m +
E 226,800 m +

N 577,000 m

N 576,800 m +

N 576,600 m +

+ N 576,400 m
+ N 576,200 m

+ N 577,000 m

+ N 576,800 m

+ N 576,600 m

+ N 576,400 m

+ N 576,200 m

+ N 576,000 m   rm 4

E 226,200 m
+ N 575,800 m

E 226,400 m+

+ E 226,600 m

+ E 226,800 m

+ E 229,000 m

E 229,200 m+

Arizona State Plane, Central   N
FLIR: white=hot;   28 May 1994   ↑
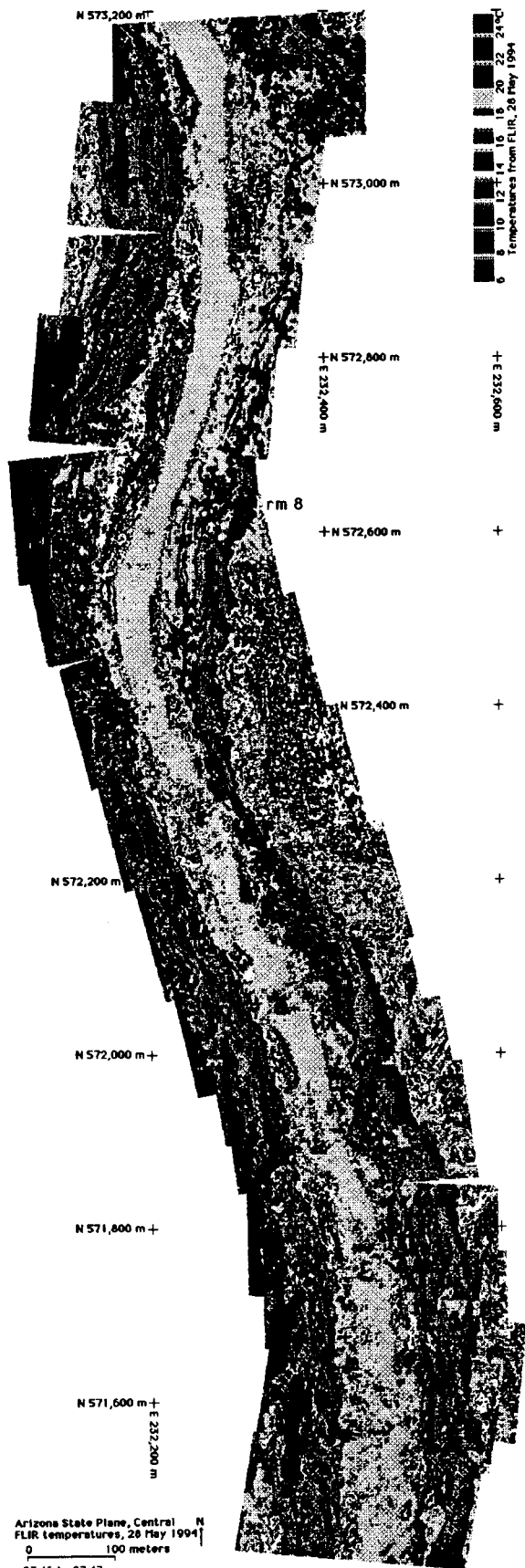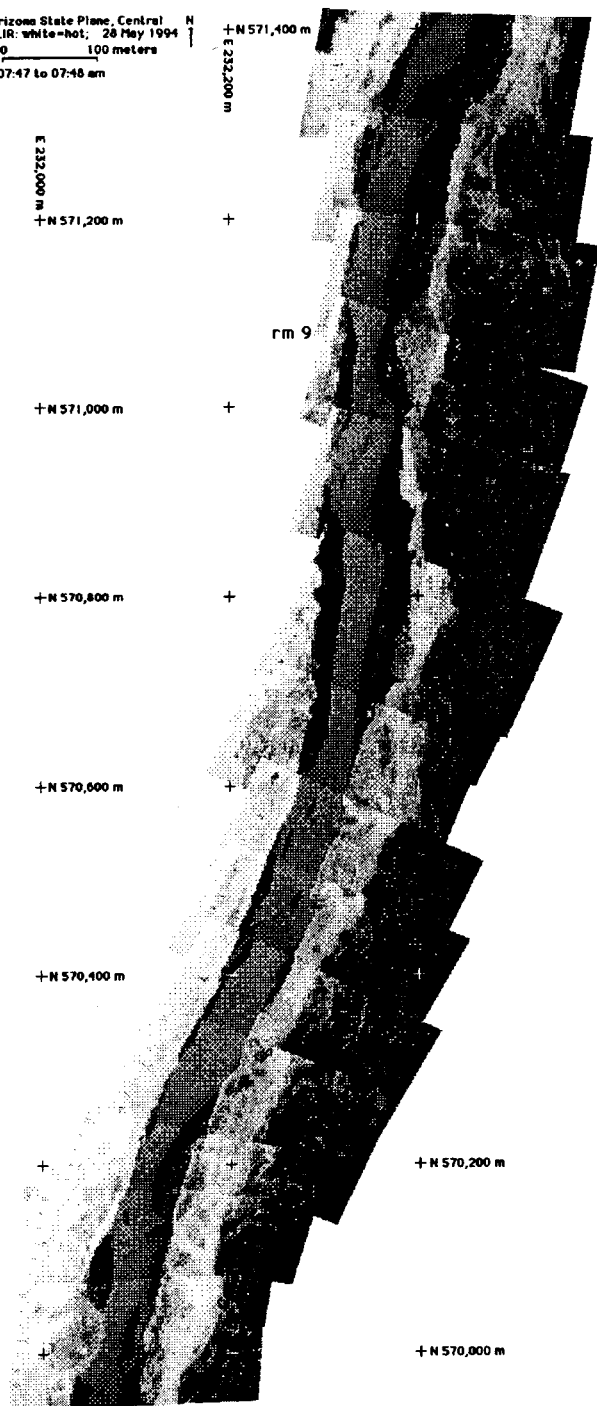0   100 meters
07:42 to 07:43 am

N 577,000 m

+ N 576,800 m

+ N 576,600 m

+ N 576,400 m

+ N 576,200 m

rm 4

+ N 576,000 m

E 229,200 m

E 228,200 m
N 575,800 m

E 228,400 m

E 228,600 m

E 228,800 m

E 229,000 m

Arizona State Plane, Central
FLIR temperatures, 28 May 1994

0   100 meters

07:42 to 07:43 am

N

0 8 10 12 14 16 18 20 22 24 °C
Temperatures from FLIR, 28 May 1994

E 230,600 m +

E 230,400 m +

E 230,200 m +

E 230,000 m +   +   rm 5

E 229,800 m +

+ N 575,800 m

+ E 229,600 m

+ E 229,400 m

N 575,600 m +

N 575,400 m + E 229,200 m

Arizona State Plane Central
FLIR: white=hot;   28 May 1994
07:43 to 07:44 am

N

0   100 meters

E 230,600 m +

E 230,400 m +

E 230,200 m +

E 230,000 m + + rm 5

E 229,800 m +

+ N 575,600 m

+ E 229,600 m

+ E 229,400 m

N 575,600 m

N 575,400 m + + E 229,200 m

Arizona State Plane, Central
FLIR temperatures, 28 May 1994

0   100 meters

07:43 to 07:44 am

Temperatures from FLIR, 28 May 1994

0   8   10   12   14   16   18   20   22   24°C

E 232,000 m

E 231,800 m
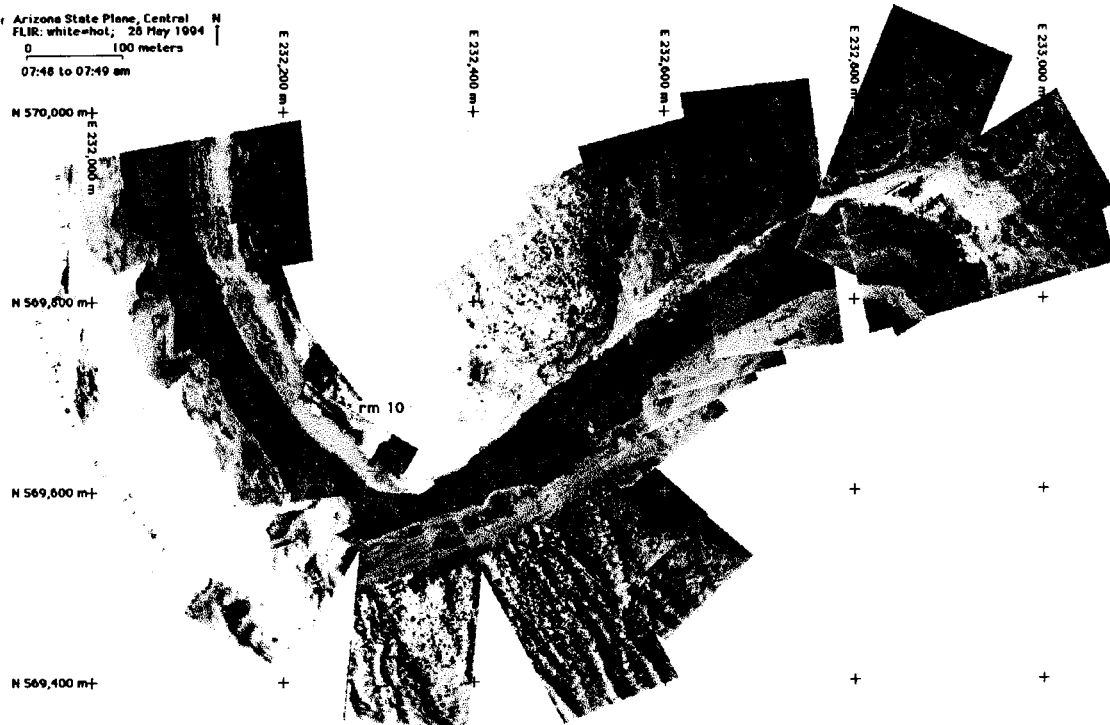
E 231,600 m

E 231,400 m

rm 6

E 231,200 m

E 231,000 m

N 575,600 m

N 574,800 m

E 230,800 m

N

Arizona State Plane, Central
FLIR: white-hot; 28 May 1994

0   100 meters

07:44 to 07:45 am

N 575,400 m

N 575,200 m

N 575,000 m

E 230,600 m

N 232,000 m labels and map figure

E 232,000 m

31,800 m

E 231,600 m

E 231,400 m

rm 6

E +N 574,800 m

E 231,200 m

+N 575,600 m

+E 231,000 m

+E 230,800 m

N 575,400 m

N 575,200 m

N 575,000 m +E 230,600 m

Arizona State Plane, Central
FLIR temperatures, 28 May 1994

N

0   100 meters

07:44 to 07:45 am

0 8 10 12 14 16 18 20 22 24°C
Temperatures from FLIR, 28 May 1994

E 232,200 m
+ N 574,800 m

N 574,600 m +
E 232,000 m

N 574,400 m +

N 574,200 m +

rm 7

N 574,000 m +

+ N 573,800 m

N 573,600 m

N 573,400 m +

+ N 573,200 m
N

Arizona State Plane, Central
FLIR: white=hot;   28 May 1994

0   100 meters

07:45 to 07:46 am

Temperatures from FLIR, 28 May 1994

0 8 10 12 14 16 18 20 22 24 °C

E 232,200 m

N 574,800 m

N 574,400 m

N 574,200 m

rm 7

N 574,000 m

N 573,800 m

N 573,600 m

N 573,400 m

E 232,000 m

N 573,200 m

N

Arizona State Plane, Central
FLIR temperatures, 28 May 1994

0   100 meters

07:45 to 07:46 am

N 573,200 m

E 232,600 m

E 232,400 m

N 573,000 m

N 572,800 m

N 572,600 m

N 572,400 m

N 572,200 m

N 572,000 m

N 571,800 m

N 571,600 m

E 232,200 m

E 232,600 m

Arizona State Plane, Central
FLIR: white=hot; 28 May 1994

N

0   100 meters

07:46 to 07:47 am

N 573,200 mT

+ N 573,000 m

+N 572,800 m
+E 232,400 m
+E 232,600 m

rm 8

+N 572,600 m   +

N 572,400 m   +

N 572,200 m   +

N 572,000 m +   +

N 571,800 m +   +

N 571,600 m +E 232,200 m +

Temperatures from FLIR, 28 May 1994

6   8   10 12 14 16 18 20 22 24 °C

Arizona State Plane, Central   N
FLIR temperatures, 28 May 1994
0   100 meters
07:46 to 07:47 am

Arizona State Plane, Central   N
FLIR: white=hot;   28 May 1994
0   100 meters
07:47 to 07:48 am

E 232,200 m

+ N 571,400 m

E 232,000 m

+ N 571,200 m   +

rm 9

+ N 571,000 m   +

+ N 570,800 m   +

+ N 570,600 m   +

+ N 570,400 m   +

+   +   + N 570,200 m

+   + N 570,000 m

Temperatures from FLIR, 28 May 1994

Arizona State Plane, Central   N
FLIR temperatures, 28 May 1994

0 —————— 100 meters

07:47 to 07:48 am

E 232,000 m
+ N 571,200 m

E 232,200 m +

rm 9

+ N 571,000 m   +

+ N 570,800 m   +

+ N 570,600 m   +

+ N 570,400 m

+ N 570,200 m

E 232,400 m
+ N 570,000 m

N 570,000 m

N 569,800 m

E 232,000 m

E 232,200 m

E 232,400 m

E 232,600 m

E 232,800 m

E 233,000 m

rm 10

N 569,600 m

N 569,400 m

E 233,000 m

E 233,200 m

E 233,400 m

E 233,600 m

E 233,800 m

N 569,800 m

N 569,600 m

E 232,800 m

N 569,400 m

N 569,200 m

N 569,000 m

rm 11

N 568,800 m

Arizona State Plane, Central   N
FLIR temperatures, 28 May 1994
0   100 meters
07:48 to 07:49 am

N 570,000 m

N 569,800 m

N 569,600 m

rm 10

N 569,400 m

E 232,200 m
E 232,000 m
E 232,400 m
E 232,600 m
E 232,800 m
E 233,000 m

6   8   10   12   14   16   18   20   22   24 °C
Temperatures from FLIR, 28 May 1994

E 233,000 m
E 233,200 m
E 233,400 m
E 233,600 m
E 233,800 m

N 569,800 m

N 569,600 m

E 232,200 m

N 569,400 m

N 569,200 m

N 569,000 m

rm 11

N 568,800 m

Arizona State Plane, Central   N
FLIR temperatures, 28 May 1994
0   100 meters
07:49 to 07:50 am

6   8   10   12   14   16   18   20   22   24 °C
Temperatures from FLIR, 28 May 1994

Arizona State Plane, Central
FLIR temperatures, 28 May 1994

0 _____ 100 meters

07:50 to 07:51 am

rm 12

N 568,800 m +

N 568,600 m +

+N 569,000 m

E 234,000 m

E 233,800 m

E 234,200 m

+ E 234,400 m

N

Arizona State Plane, Central
FLIR: white=hot; 28 May 1994

0 _____ 100 meters

07:51 to 07:52 am

N

E 233,800 m

E 233,600 m

rm 12

N 568,600 m +

N 568,400 m +

N 568,200 m +

N 568,000 m

N 567,800 m

N 569,000 m +

E 234,000 m

N 568,800 m +

E 234,400 m +

rm 12
N 568,600 m +

E 233,800 m

E 234,200 m
+

Arizona State Plane, Central
FLIR temperatures, 28 May 1994

0   100 meters

07:50 to 07:51 am

0 8 10 12 14 16 18 20 22 24 °C
Temperatures from FLIR, 28 May 1994

Arizona State Plane, Central   N
FLIR temperatures, 28 May 1994

0   100 meters

07:51 to 07:52 am

E 233,800 m

E 233,600 m

rm 12

N 568,600 m +

N 568,400 m +

N 568,200 m +

N 568,000 m

N 567,800 m

Temperatures from FLIR, 28 May 1994

0 8 10 12 14 16 18 20 22 24 °C

N 567,800 m

+ N 567,600 m

E 233,800 m

E 234,000 m

E 233,600 m

N 567,400 m

N 567,200 m

E 233,400 m

rm 13

Temperatures from FLIR, 28 May 1994

6 8 10 12 14 16 18 20 22 24 °C

Arizona State Plane, Central   N
FLIR temperatures, 28 May 1994
0   100 meters
07:52 to 07:53 am

N 567,800 m

+ N 567,600 m

+ E 233,000 m

+ E 233,800 m

+ E 234,000 m

N 567,400 m

N 567,200 m + E 233,400 m

rm 13